The importance of R&D: Is the Barcelona 3% a reasonable target?

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The importance of R&D: is the Barcelona 3% a reasonable target?

Mijnheer de Rector Magnificus,
Geachte collega's en vrienden,

Het is nu drie jaar geleden dat ik werd benoemd tot hoogleraar op onze universiteit. Toen was ik verbaasd over twee dingen. Het eerste was dat het gebruikelijk was dat ik een oratie zou houden. Dat was in Canada, waar ik daarvoor hoogleraar was, helemaal niet het geval. Dus neemt u het me niet kwalijk dat het zo lang heeft geduurd om deze oratie te houden. Mijn tweede verrassing kwam op mijn tweede trainings-sessie voor probleem gestuurd onderwijs, toen ik, als op een vraag die mij gesteld werd, een beetje ontmoedigd, met excuses voor mijn gebrekkelijk Nederlands, in het Engels antwoordde. Opeens was het gedaan met mijn vrije les Nederlands: iederen van de twintig or zo deelnemers, zonder enkele instructie van de trainer, schakelde over naar het Engels. Zo'n spontaan, natuurlijk respect voor een vreemdeling als het ware vondt ik uitzonderlijk. Ik zal dit principe vandaag ook aanwenden en de rest van mijn oratie in het Engels presenteren.

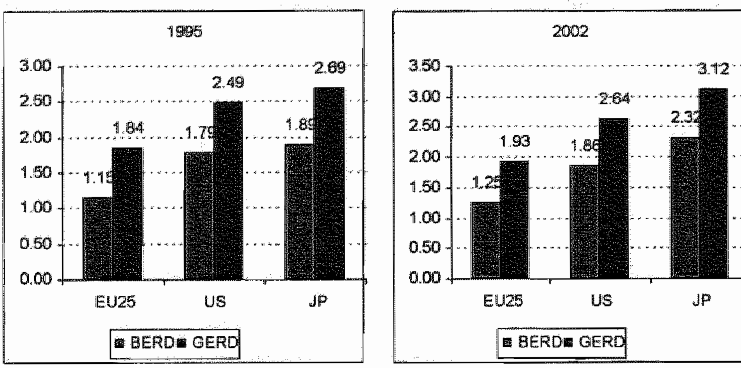
The issue

Europe as a whole (the EU-25) is trailing behind the United States and Japan in terms of R&D expenditures. As shown in figure 1, in 2002, research and development (R&D) as a proportion of gross domestic product (GDP) was 1.93% in the EU-25 whereas it was as high as 2.64% in the United States and 3.12% in Japan. The R&D gap between Europe and its main trading partners has not changed a lot since 1995.

Since conventional wisdom has it that R&D is considered as a key factor for economic growth and competitiveness, this was enough to ring the alarm bell at the European Commission. In 2002, at the Barcelona European Council, Heads of State and Government of the EU-15 (at that time) member countries concurred that R&D expenditures as a proportion of gross domestic product (GDP) had to rise from 1.9% to 3% by the year 2010, with business R&D funding accounting for two thirds of total R&D. The United States were close to 2% for business funded R&D, Japan was at 2.3%, but Europe was only at 1.25%.

I would like to analyze with you whether this fear is well founded, whether the 3% R&D/GDP ratio is a reasonable target, and whether it is reachable by the year 2010.

Figure 1: R&D/GDP (in percentages) for business expenditures on R&D (BERD) and total expenditures on R&D (GERD).



Source: Eurostat

Why is R&D important?

In the economic literature R&D plays an important role in at least two different ways. First, in the theory of industrial organization and also in the theory of international trade R&D is seen as a strategic variable by which firms conquer, or at the least preserve, market shares, and governments give their domestic firms a competitive edge in international trade, either through cost reductions (in the case of process R&D) or through product differentiation (in the case of product R&D). Second, in growth theory and in the management literature R&D is seen as an investment in knowledge or in absorptive capacity and hence indirectly as a contributor to economic growth. I want to concentrate on the second aspect.

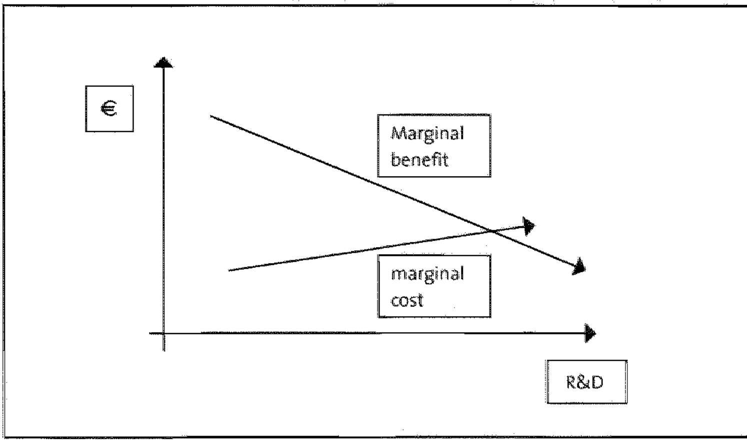
How can R&D contribute to economic growth? Remember Robinson Crusoe. He is stranded on his island and has to find ways to survive. First he uses his own labor to grow fruits and vegetables and to catch fish. Economists would call this the labor input. Then, he figures out that by devoting some of his time to make better fishing rods and agricultural tools he is able to raise his productivity: grow more vegetables and catch more fish with the same amount of effort. The equipment used to produce other commodities is what economists call the capital input. So far Robinson has spent 20% of his time producing capital equipment and 80% of his time fishing and harvesting. Now that he produces enough to survive, he starts spending some time away from production, thinking about producing ever more performing production equipment or new varieties of crop. Robinson Crusoe has discovered the power of research. From now on he spends 20% of his time producing capital equipment, 10% of his time thinking and 70% of his time fishing and harvesting. We could complicate the story but let's leave it at that and remember from this simple story that production has been obtained by using three inputs: labor, capital and R&D.

R&D plays a central role in the new theory of economic growth, called endogenous growth theory, which is based on the idea that growth does not fall like manna from heaven but can be explained by R&D efforts leading to new products (consumer goods or investment goods) and new knowledge (see the work by Romer (1990), Arrow (1962), Grossman and Helpman (1991), and Aghion and Howitt (1998)). R&D has two properties that set it apart from ordinary investment in machines, namely the fact that the knowledge derived from R&D is non-rival and partly non-excludable, which means that knowledge can be used simultaneously by two different persons without losing any of its content, and that it cannot always be prevented from being used by others. Hence the innovator cannot appropriate all the benefits from his new ideas. Part of it leaks out to others. In practice R&D has two effects. It can lead to new commodities, on which the innovator gains temporary monopoly profits (i.e. profits derived from the fact that he is the own producer, without competitors driving the profit down to zero), and it can lead to new knowledge (in the form of theorems, algorithms, models), which can facilitate subsequent innovations. Because of the impossibility of perfect price discrimination, a part of the monopoly rents get transferred to other producers or the consumers. For instance, we all seem to derive a benefit from using computers which is greater than the price that we paid for acquiring them. Zvi Griliches (1979) called this first R&D spillover "rent spillover" to distinguish it from the second one, which has to do with the free transmission of knowledge and which he called "knowledge spillover". The non-appropriability of the entire benefits from R&D and the intertemporal externalities of R&D keep the benefits of R&D from dropping below the discount rate and hence maintain the incentives to invest in R&D, and therefore assure sustained growth.

What is the optimal level of R&D?

In the extended production function R&D appears as an input side by side with labor and capital. To simplify things, production is explained by the intensity and the combination of use of two basic factors of production, labor and capital (buildings, machines and equipment), and the stock of knowledge measured by the accumulation of past and present R&D expenditures, also sometimes called R&D capital. If we suppose that R&D is chosen in each period so as to maximize profit, the optimal amount is achieved when the marginal benefit of an additional eurocent spent on R&D equals the marginal cost of such an investment. If we refer to figure 2, we have on the vertical axis the € amounts of costs and benefits and on the horizontal axis the amount spent on R&D. The upper curve which is downwards sloping represents the evolution of the marginal benefit as R&D increases and the bottom, slightly upward sloping, curve represents the marginal cost of each additional unit of R&D. Implicitly I have made the usual assumptions of neoclassical economics that the marginal productivity decreases and the marginal cost increases with the amount of R&D expenditures. It corresponds basically to the intuition that you need to do more and more research to find less and less. This assumption can be criticized but, for the argument's sake, let's keep it for the time being. As long as the marginal benefit curve stays above the marginal cost curve each additional amount of R&D yields a profit, when the two curves intersect marginal cost equals marginal revenue and hence the benefits just match the costs at the margin and when the marginal benefit curve drops below the marginal cost curve, the additional unit of R&D costs more than it delivers in revenues. This is economics 101.

Figure 2: The optimal level of R&D



If we give the extended production function a Cobb-Douglas functional form

$$Q=AL^{\alpha}K^{\beta}R^{\eta} \tag{1}$$

where Q is output, L is labor, K is the physical capital stock, R is the R&D stock, A is a parameter that represents the level of technology, and α, β and η are respectively the output elasticities of labor, capital and R&D, i.e. they represent by how much output increases in percentages when labor, capital and R&D respectively increase by a given percentage. The marginal productivity of R&D, $\gamma = (\partial Q/\partial R)$, is then given by

$$\gamma= \eta(Q/R). \tag{2}$$

As already mentioned, it is the accumulated stock of R&D (R) and not the actual R&D expenses (I_{Rt}) in a given year that should enter the production function. Suppose that the R&D stock of knowledge accumulates according to the perpetual inventory method:

$$R_t=(1-\delta)R_{t-1} +I_{Rt} \tag{3}$$

where δ is the R&D depreciation rate. Consequently, a firm benefits from the knowledge acquired in the past and conversely the additional knowledge gained from today's R&D will bear fruit immediately but also in the future. As the stock of knowledge accumulates it also depreciates like any machine or durable good. Scientists die and carry with them untransmittable (so-called tacit as opposed to codified) knowledge, and old knowledge becomes obsolete and gets superseded by new knowledge. Hence future costs and benefits need to be discounted (in discrete time, they have to be multiplied by $1/(1+r)$, where r is the risk-free interest rate, in continuous time by e^{-rt}) and the R&D stock depreciates (by $1/(1+\delta)$ in discrete time, $e^{-\delta t}$ in continuous time). In this example, it is assumed that the R&D depreciates exponentially over time, hence its lifetime is so to say infinite.

The optimal amount of R&D is given by the following equality

$$p_R=\int_0^{\infty} e^{-(r+\delta)t}\,\gamma\,dt, \qquad (4)$$

which states that the price of a unitary investment in R&D (p_R) equals the present value of all discounted future marginal productivities of the undepreciated remainders of the initial R&D investment. If we assume that the marginal productivity (the rate of return) of R&D stays constant over time, then solving this equation yields that

$$p_R(r+\delta)=\gamma. \qquad (5)$$

and if we assume to be at the steady state, where the stock of knowledge remains constant ($R_t=R_{t-1}$) and hence from (3) the R&D investment just serves to keep the stock of knowledge at its steady state level, we have:

$$I_{Rt}=\delta R_t. \qquad (6)$$

If we combine the two expressions (2) and (5) for γ and make use of expression (6) we can solve for I_R/Q, which in macroeconomic terms is precisely the famous R&D/GDP ratio, and we get

$$I_R/Q=\eta\delta/p_R(r+\delta). \qquad (7)$$

This formula provides a first approximation of the optimal R&D/GDP ratio. This optimum depends on the purchase price of R&D and on three parameters: the R&D elasticity of output, the risk-free interest rate and the rate of R&D depreciation.[1]

Now let us calibrate this expression to see what the optimal R&D intensity should be.

Regarding the R&D deflator (p_R) there is no loss of generality in putting ourselves at the base year, where the deflator is equal to 1. In some countries, R&D performing firms benefit from R&D tax incentives or direct government aid in the form of subsidies or government contracts.[2] If we add direct and indirect aid for R&D, the effective price for one euro of R&D might be of the order of 50 or 60 eurocents. This concerns the price faced by individual firms. However, at the economy-wide level these various forms of aid are borne by the government and cancel out.

As a matter of fact, there are at least two reasons why the cost of one euro of R&D might actually be higher than one euro. First, there might be an opportunity cost for investing in R&D, for instance if scientists are transferred from education to research or if funds earmarked for R&D reduce the health services or cultural activities. The second reason is a bit more intricate. The static optimization rule that we have used so far to determine the optimal amount of R&D, while powerful and intuitive, is a bit simplistic. I don't have to convince you that it takes time to understand, to discover, to innovate. It is therefore more reasonable to think in terms of intertemporal optimization. In this case, the optimal amount of R&D is no longer obtained by maximizing a given year's profit (as in static maximization) but by maximizing over a sequence of decisions, taking into account the influence of today's decisions on tomorrow's costs and benefits. Notice that in an intertemporal setting the optimum is still determined by a matching of marginal costs and marginal benefits but now over a given time period. Dynamics can be rationalized by the existence of adjustment costs, time to innovate,

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1 To simplify the presentation, I have dropped time subscripts whenever it was not essential to have them.

2 J. Warda (2002) has computed for various countries an effective price of R&D index, the B-index, that takes into account various forms of R&D tax incentives. Some countries, like Spain, offer high tax incentives, others, like Germany, rely exclusively on direct aid to stimulate R&D.

expectations, irreversibility. In Mohnen (1992) I have estimated on Canadian macro data such a dynamic model of R&D determination based on adjustment costs. In that case, what essentially changes in the optimal decision rule is the addition to the purchase price of the marginal adjustment cost. The marginal adjustment cost was estimated to range from 30% to 60% of the purchase price. Similar orders of magnitude have been found in other studies.

The depreciation of the R&D stock (δ) is often fixed arbitrarily at 10% or 15%. These orders of magnitude are consistent with the estimates obtained by Bosworth (1978) on the basis of patent renewal data. Pakes and Schankerman (1984) estimate an average rate of 25% also from patent renewal data, and recently Bernstein and Mamuneas (2005) estimate industry-specific rates that range from 18% for chemicals to 29% for electrical products.

As to the risk-free interest rate (r), the government bond rate or the shadow interest rate that the Dutch tax authorities assume the taxpayer makes on his wealth could serve as appropriate proxies. The rate is nowadays roughly 4%, it has been higher in the past. Let us fix it at 5% to simplify our computations.

The R&D elasticity of output (η) indicates by how much output increases in percentages when R&D increases by one percent. It is not directly observable, but needs to be estimated. Starting with the pioneering work by Zvi Griliches and Ed Mansfield in the late 50s economists have tried to estimate the magnitude of the impact of R&D on economic growth. The estimates can represent rates of return, i.e. what is the yield of an investment of one euro in R&D, generally in terms of additional output. Some estimates are in expressed in output elasticities, i.e. what is the percentage of increase in output brought about by a one percentage increase in R&D. And finally some studies prefer to quantify the magnitude of the impact by calculating the contribution of R&D to output or productivity growth, i.e. cutting the increase of the cake in pieces and attributing a certain portion of the total to R&D. The three types of measurement are interrelated in the sense that knowing one allows you to compute the other two.[3]

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3 There is a subtle difference in assuming a constant rate of return or a constant R&D elasticity of output.

At first sight, the estimates vary quite a bit across studies: the rates of return can vary between 10% and 80%, the elasticities between 0.05 and 0.25 and the contribution of R&D to productivity growth from 10% to 50%, excluding the cases where no significant link at all is obtained. Although this wide range of estimates may shed some doubt on our ability to estimate correctly the return to R&D, we can actually narrow down the range of estimates and propose some reasonable values. The estimates may differ for three groups of reasons (see Mairesse and Mohnen, 2003).

First, there can be a difference in the modeling. Most of the studies have estimated an extended Cobb-Douglas production function. In this case, a constant R&D elasticity of output is estimated. Other studies estimate a more general functional form allowing the elasticity to vary with size or input prices. Yet other studies induce the estimates not from a production function but from a function linking, for instance, the total production costs due to labor and capital to the prices of labor and capital and the output to be produced. This approach, called the dual approach, assumes all inputs (or at least some of them) to be optimally chosen and reverses the role of some of the variables. Output for instance is now taken as given and total cost is the variable to be explained. It is also possible to increase the amount of information used to estimate the return on R&D by estimating together with the technology equation the equations for factor demands. This makes the estimates more efficient but at the price of a potential misspecification. Recent work, to which I shall return later, has modeled the endogeneity of R&D itself, that's to say the idea that R&D itself depends on such things as size, technological opportunity (the chance to find something), the pressure of competition, etc. Hence it may be that productivity and R&D are correlated because they both increase with competition. In that case the story it not that R&D causes productivity but rather that R&D and productivity are both caused by a third common factor. Accounting for this common determinant may decrease the marginal effect of R&D.

The second difference among the empirical studies on the returns to R&D has to do with the data that are being exploited. We can distinguish four issues: the level of aggregation, the type of variation, the kind of sector or R&D, and the possible selectivity.

(i) Aggregation. You can use country wide data, industry data, firm data or project data. Depending on the level of aggregation of the data, the estimate will capture only the return to the enterprise or the return to society, i.e. include or not the R&D spillovers. The measurement errors, e.g. in prices, which indirectly determine the quantities given the total factor payments, may be more acute at the micro level than at the macro level.

(ii) Type of variation. The econometrician relates the variations in output to the variations in R&D. If output does not change when R&D goes up or down, then there is hardly any sign of a return to R&D. If however the two are strongly correlated, after accounting for the variations in output due to labor and capital, or anything else that could affect output separately from R&D, then the econometrician would conclude that there is an R&D effect revealed by the data. There are two types of variations in the data: the temporal variation and the cross-sectional variation. In the former you relate changes over time in the variable to be explained and the explanatory variables. In the latter it is variations across industries, countries, firms, etc. at a given moment in time that are used to make statistical inference. Typically, temporal variations are marred by problems of cyclical shocks, incomplete adjustments (firms have not had time to adjust their inputs, in particular R&D, to their optimal levels given changes in the economic environment, or it was too costly for them to do so) and measurement errors. Results in the temporal dimension are therefore more likely to reflect short-term effects. Cross-sectional variations, e.g. differences in output and research expenditures between low-tech (with little R&D) and high-tech (R&D intensive) industries, are closer to long-run effects.[4]

4 There are also intermediate cases. For instance instead of taking annual changes you can consider calculating growth rates over a five-year time span. Here variations are more likely to correspond to medium-run or even long-run effects. If you are in the presence of time-series on cross-sections, e.g. annual observations for 100 firms over a ten-year period, then you have what is called panel data, which contain both kinds of variation. If you use the firm averages over the ten-year period, you are left with the cross-sectional variation. If you transform the data in deviations from individual means to eliminate the unobservable individual effects, then you are left with the temporal variation. The returns estimated on the temporal variation tend to be lower than those estimated on the cross-sectional variation, because of the incompleteness of the short-term effects (it takes time for the whole effect to materialize and show up in the data) and because of the presence of more noise in the temporal variation.

(iii) Type of sector and type of R&D. Firms in high-tech sectors such as chemicals or transportation equipment have typically higher returns than those in low-tech sectors such as wood or food. This could be due to technological opportunity but also to measurement issues (the prices and hence the quantities of output and certain inputs are corrected for quality changes in some sectors and not in others). The type of R&D can also make a difference. Higher returns are obtained for basic research than for applied research, higher returns also for privately funded R&D than for publicly funded R&D and for processes than for products.

(iv) Possible selectivity. If data relate to enterprises, it is important not to limit the analysis to R&D performing firms only. This could lead to a so-called selection bias. R&D performing firms have something that distinguishes them from non R&D performing firms (they may be better performing to start with) and that by itself could explain part of the high returns to R&D. This point is related to the endogeneity argument mentioned earlier.

The third difference in the estimates is related to the nature of the effects that are being captured, i.e. the private returns for the R&D performer or the sum of the private returns and the spillover effects on other units of the economy. Spillovers are an important feature of research and development, as outlined above. Spillovers can take place between firms, industries and countries. As mentioned before, the higher the level of aggregation, the more the returns include R&D spillovers. In order to estimate spillover effects, an external R&D capital stock has to be included in the production function. There are many ways to do this. One general approach is to measure outside R&D by an index of the R&D done by the other R&D performers by weighting the individual outside R&D stocks by some kind of proximity measure (be it by the proportion of commodity exchanged or technological transactions, or by similarities in the type of R&D performed, the type of patents applied for, or the type of qualification in the R&D personnel). The other approach is to include separately the most important sources of outside R&D stocks, which may vary from sector to sector. Besides the interspatial spillovers there are also intertemporal R&D spillovers. The R&D of today can serve as a basis for building up knowledge tomorrow. This corresponds to the idea of sequential innovations, the "standing on the shoulders of giants" argument, that is brought forward in many theoretical papers.[5] One way of accounting for it would be to reduce the rate of obsolescence: even if new products come up and render the old ones obsolete, the knowledge gained from the R&D that lead to new products is not lost and can be used in the future.

If we put less weight on certain studies that are suspected to be flawed, subject to potential biases, using smaller data sets or older and less representative data, then we can narrow down the estimates to a reasonable range of values. This is what Jacques Mairesse and I have done in surveying the literature (see Mairesse and Mohnen, 2003). It seems reasonable to us to quantify the private rate of return on R&D at 10%-20%, the social rate of return between 1.5 to 2 times higher than the private rate of return, the R&D elasticity at 0.05 to 0.1 and the contribution of R&D to total factor productivity growth at no more than 10%.

Given these calibrations, we can by simple back-of-the-envelope calculations compute what the optimal R&D/GDP ratio should be under different combinations of the parameters determining that optimum. In table 1 we present the results of these calculations for 4 values of the R&D depreciation rate, 4 values of the output elasticity of R&D and two values of the marginal cost or effective price of R&D.

I hope that I have convinced you that given our knowledge of the order of magnitudes of the parameters that determine the optimal R&D/GDP ratio, the 3% target is not more justified than would be a 4% or 5% target. It is likely that 3% is actually an underestimate of what the optimal R&D intensity should be. Probably European policymakers set a target slightly higher than the R&D/GDP ratio in the United States, with an anticipation of an upward trend.

5 See Jones and Williams (1998).

Table 1 Sensitivity of optimal R&D/GDP to various parameter values (in %)

η	p_R	δ=0.10	δ=0.15	δ=0.20	δ=0.25
0.05	1.0	3.33	3.75	4.00	4.17
	1.5	2.22	2.50	2.67	2.78
0.075	1.0	5.00	5.63	6.00	6.25
	1.5	3.33	3.75	4.00	4.17
0.10	1.0	6.67	7.50	8.00	8.33
	1.5	4.45	5.00	5.33	5.55
0.15	1.0	8.33	9.38	10.00	10.42
	1.5	5.55	6.25	6.66	6.94

Should we not look at innovation output rather than innovation input?

With the declaration of the Barcelona Summit the attention has perhaps focused too much on research and development. First, R&D is just one input in innovation and technological change. Actually, even if we just concentrate on R&D, the official definition of R&D that is widely accepted in statistical offices is restricted to "creative work undertaken on a systematic basis to increase the stock of knowledge and the use of it to devise new applications". It excludes lonely inventors, informal R&D such as on the floor marginal improvements in machinery. It also excludes market research, marketing costs for the promotion of new products, the purchase of patents, training, attending conferences. The evolutionary theory of technological change emphasizes the role of various sources of learning (learning-by-doing, learning-by-using,...) in explaining technical progress. Unfortunately the statistics presently gathered on other than R&D innovation inputs are not sufficiently reliable to make sensitive comparisons.

Second, what really matters is not so much the amount of R&D effort as the output of that R&D effort. Innovation output can take the form of patents, publications, citations, the introduction of new products on the market, the adoption of new production processes or re-organizations of business operations. Publications and patents, unless weighted by citations for instance, do not distinguish good from bad. Patents moreover suffer from differences in patent propensities across industries. Table 2 compares the European Union with the United States and Japan on the basis of various innovation input and output criteria. Europe lags behind especially in business expenditures on R&D but also in public expenditures on R&D. On the output side, Europe is outperformed by the US on all scores, except the percentage of new S&E graduates. Compared to Japan the evidence is more mitigated: Europe scores worse in patenting, but better than Japan in publications (including its quality, measured by citations). Japan might have a language disadvantage. According to a study conducted by John Hagedoorn and Myriam Cloodt (2003), the innovation output measures are highly correlated with the R&D data.

Table 2 Comparison of innovation indicators: EU, US, Japan

	EU-25	US	Japan
USPTO patents granted (per million population)*	59.9	301.4	273.9
USPTO high-tech patents granted (")*	9.4	76.4	75.4
EPO patent applications (per million population)*	133.6	154.5	166.7
EPO high-tech patent applications (")*	26.0	48.4	40.4
Number of triad patents (")	27.6	42.4	68.5
% of manufacturing value-added in high-tech sect.*	12.7	23.0	18.7
Scientific publications per million	613	708	498
% of highly cited papers in total number of citations	1.20	1.27	0.65
New S&E graduates (% of 20-34 years age class)	6.85	6.37	8.66
Seed and start-up venture capital (per million pop.)	0.38	1.16	0.99
Public R&D expenditures (% of GDP)*	0.67	0.86	0.80
Business expenditures on R&D (% of GDP)*	1.27	1.90	2.32

Source: Innovation scoreboard 2004, Trendchart (*), EU Commission and Nauwelaers, Veugelers and Van Looy (2003)

One could also argue that it is not just a matter of doing R&D but also of doing good R&D. It would be better to compare not just the amount spent on R&D but also the productivity of R&D. The latter could depend on the extent of R&D externalities and on the composition of R&D (basic research yields higher returns than developmental research, process R&D higher returns than product R&D). Fifteen years ago Mansfield (1988) compared the R&D outcomes in the United States and Japan and concluded that the Japanese were gaining higher returns than the Americans from applied R&D because of the greater reliance on imported technology and process R&D as opposed to product R&D. Bilateral comparisons have been made between some European and American countries. It would be interesting to conduct a systematic analysis comparing the returns from a representative sample of American and European firms.

For the last ten to fifteen years, innovation surveys have been launched in the European Community and other OECD countries. Unfortunately, no such survey has been done for the United States. The idea is to measure innovation by the percentage of enterprises that introduce new products or processes, and possibly a quantification of the innovation intensity, as measured for example by the share in total sales due to innovative products. This measure is somewhat subjective, it is perhaps not defined in a crystal-clear way and it measures not just technical innovation but also marketing performance, but it has the advantage to measure the success in bringing new products on the market. In ongoing work, using the evidence from the innovation survey data, Jacques Mairesse and I find that R&D is a good predictor of innovation intensity and that innovation output intensity has a significant effect on productivity growth. We also find that process innovations have a higher marginal effect on productivity than product innovations.

Is 3% reachable by 2010?

Member States and the EU Commission have launched studies and set up expert groups to find out how to reach the 3% target. Policies have been introduced to boost private R&D efforts and to increase public R&D spending. Provisional figures based on anticipated trends suggest that the EU/US R&D gap is closing but that this owes more to the slow R&D growth in the US than to an improvement in EU performance, that public R&D funding is too low to reach the 3% target by 2010, and that China and India are busy closing their technological gap.

As the literature on national systems of innovation warns, it is not wise to concentrate on a single policy measure. Instead, it is useful to see innovation in a systemic or general equilibrium perspective with various actors, institutions and policies interrelated and feeding onto each other. In a joint paper Lars-Hendrik Röller and I (2005) showed that there are complementarities in innovation policies, in the sense that working on various fronts simultaneously allows you to achieve more than just concentrating on one policy. For instance, it makes little sense to try and foster innovation by handing out generous R&D tax incentives, if there is a fundamental lack of scientists, technicians, and qualified personnel.

It will only increase the salary of R&D workers, not the amount of research. Hence it is very important to work on the creation of human capital, to attract scientists to Europe rather than losing them, and to enhance labor mobility. It is also important to have sufficient venture capital, access to finance for innovators: table 2 reveals blatantly that Europe does worse on that front than either Japan or the United States. Other studies (see Paul David, Bronwyn Hall and Andrew Tool, 2000) have found signs of complementarity between public and private R&D, although the evidence is not entirely conclusive. All these elements are well accepted and put into practice by European policymakers.

So what is the problem in Europe? It is often said about Europe that its research is pretty good, the "matière grise" is there, but what is lacking is a culture of entrepreneurship and an environment conducive to taking risks. According to the Global Entrepreneurship Monitor 2002, there are less than half as many entrepreneurs involved in startups and owner-managers of firms less than 42 months old in Europe than in the United States and according to the Eurobarometer, 2001 only 45% of the population has a preference for self-employment in Europe against 67% in the US. The regulatory hurdles may explain part of the difference. The World Bank reported in 2003 that it took 45 days on average in Europe to start a business against only 4 days in the United States.

There are differences in R&D intensities across European countries. Some countries like Finland and Sweden have already reached the Barcelona 3% target, while the mean ratio for the EU-25 hovers around 2%. The aggregate difference in R&D intensity between two countries can be decomposed into a structural composition effect and an intrinsic R&D intensity difference effect. Some industries like pharmaceuticals or machinery and equipment are more R&D-intensive than others like wood or textile. Hence depending on the industrial composition of economic activity the aggregate R&D intensity can be very different. Hence it does not make much sense to expect every EU country to achieve the same 3% target. However, in the major countries of the EU-25 the average industrial structure is not that different. Peter Teirlink (2002) for Belgium and Hugo Hollanders and Bart Verspagen (1999) for the Netherlands reach the same conclusion: 75% of the difference of their respective country's R&D intensity compared to a number of other OECD countries is due to the intrinsic difference of R&D intensity at the sectoral level and only 25% is due to a composition effect.

Of course, one could also argue that this industrial composition is not exogenous, nature-given, but depends on the amount invested in R&D. Actually it could also be argued, although it is probably a little bit far fetched, that some countries benefit more from R&D spillovers than others, and hence can partly rely on the R&D done by others. To some extent this can be the case, but a central result in innovation analysis should never be forgotten: to benefit from R&D spillovers, you must have an absorptive capacity and for that you need to do some R&D yourself (see Cohen and Levinthal, 1989). It is true that some countries may have a comparative advantage in R&D. There is nothing wrong about specializing and about having some countries do more R&D to keep up with their competitors than others. Actually the magic target should hold for the European Research Area as a whole and not necessarily for each individual member country. According to specializations, cluster effects, synergies and idiosyncracies, some countries will do more fundamental research, others more development or simply less R&D of any kind but more marketing.

Politicians and commentators often lament about the brain drain and the exodus of R&D to other countries. Indeed more EU financed R&D is executed in the United States or Japan than vice-versa. But apart from the concern of keeping human capital active in Europe, why is it so important to have the R&D executed at home rather than abroad? In the end the importance is in the use, not in the production, of R&D.

Given the time it takes to adopt policy measures, given the adjustment costs linked to R&D investments (as indicated previously), given also the constraints imposed by the Stability Pact, it is not surprising that progress is slow. It is also true that as we move towards the target, two things can happen: first, other countries will react and try to keep their advantage (we are in a sort of prisoner's dilemma situation), and second, the other countries, in particular the United States, benefit from the additional European R&D (the Meister and Verspagen (2004) argument).

Conclusion

I suggest that you can take home two conclusions. The first is that R&D is useful for society. It builds up knowledge and it is one of the key inputs for innovation. But R&D is not a goal in itself, it is only a means to achieve a higher standard of living. The second is that the Barcelona

3% target is economically not more justified than would be a 5% target, but if the 3% signal is sufficient to put R&D high up on the EU political agenda, it is a smart choice.

Words of thanks

On this optimistic note, I would like to conclude my inaugural lecture and say a few words of thanks to a number of people. First, I would like to thank het College van Bestuur and the Faculty Board of Economics and Business Administration for the trust they put in me in offering me this professorship position. In particular, I would like to thank two persons, Franz Palm, who welcomed me in the section of econometrics and with whom I have an enormous pleasure to collaborate, and Luc Soete, whose enthusiasm, creativity and entrepreneurship are hard to beat. Both of you have managed to offer me a very attractive package deal: being able to do research on innovation and new technologies but also on the development and application of econometric techniques. It is great to be able to share my time between the department of quantitative economics and MERIT, especially in the new MERIT/INTECH environment. Those are two different worlds but in my case very complementary. Thank you also to all the members of the two sections, the colleagues, the support staff, in particular Wilma who is always there to help in many ways, and finally the students, with their very diversified background and challenging questions.

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Finally, I would like to thank first and foremost my parents for their never ending love, support, and encouragement. Myra and Paul, sorry for spending so much time behind my books and computer screen instead of sharing the precious time with you. Barbara, I hope that today's talk explains to you a bit better what I am doing and why I like it. Thank you for letting me pursue my research interests. I'll make it up one day.

Ik heb gezegd.

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